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U. S. PATENT APPLICATION

for

CORRECTION OF DEFECTIVE PIXELS IN A DETECTOR

Inventors: Richard Aufrichtig
Ping Xue
Kenneth S. Kump

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CORRECTION OF DEFECTIVE PIXELS IN A DETECTOR

BACKGROUND OF THE INVENTION

The present invention relates generally to detector systems. More particularly, the present invention relates to a detector system equipped to correct defective pixel values therein.

A solid state detector contains a plurality of photodetector elements. For example, a radiographic x-ray detector can include several million photodetector elements to correspondingly provide an image having several million pixels. Such a detector typically comprises a scintillating layer in contact with an array of photodiodes arranged in rows and columns. Each photodiode converts impinging light into an electrical charge or signal proportional thereto, and in turn, each electrical signal is processed and converted into a digital value. The resulting array of digital valves comprise the image data for the image to be displayed.

In the course of manufacturing such a detector, a certain number of photodetector elements will invariably be defective. Because pixel size is chosen such that objects of interest in the image will be greater than the size of an individual pixel, a perfect detector is not required for imaging. However, if defective or bad pixels are aggregated in sizeable clusters, the loss of relevant information may be considerable. Alternatively, since defective pixel values would either be independent of the impinging light, because the corresponding detector locations are not photonically and/or electrically responsive, or be dependent of the impinging light but in manner statistically different from its neighboring pixels, if defective pixels are left unaltered in the displayed image, they would distract from the visualization of the rest of the image.

Presently, there are known methods for identifying and correcting defective pixel values prior to displaying the image. These correction methods replace each defective pixel value with an interpolation of its neighboring pixel values. Such correction methods, however, are quite susceptible to creating image

artifacts, such as breaks in guide wires, because the correction relies only on the defective pixel's surrounding pixels, i.e., the eight pixels surrounding the defective pixel.

Thus, there is a need for a correction method that provides a more accurate correction of defective pixels. Further, there is a need for an apparatus and method configured to utilize image feature information to perform defective pixel correction.

BRIEF SUMMARY OF THE INVENTION

One embodiment of the invention relates to a method for correcting a defective pixel in an image produced by a detector. The image includes an array of pixels and the array of pixels has a corresponding array of pixel values. The method includes determining a local gradient, the local gradient comprising an array of local gradient matrix elements. The method further includes providing a correction value based on the local gradient to correct the defective pixel.

Another embodiment of the invention relates to a system for correcting a defective pixel in an image produced by a detector. The system includes a processor coupled to the detector, the processor configured to determine a local gradient and to generate a correction value based on the local gradient. The image includes an array of pixels, each pixel having a corresponding pixel value, and the local gradient comprises an array of local gradient matrix elements.

Still another embodiment of the invention relates to a system for correcting a defective pixel in an image produced by a detector. The image includes an array of pixels, the array of pixels having a corresponding array of pixel values. The system includes means for determining a local gradient, the local gradient comprising an array of local gradient matrix elements. The system further includes means for providing a correction value based on the local gradient to correct the defective pixel.

BRIEF DESCRIPTION OF THE DRAWINGS

The preferred embodiment will become more fully understood from the following detailed description, taken in conjunction with the accompanying drawings, wherein like reference numerals denote like elements, in which:

FIG. 1 is a block diagram of a solid state detector imaging system which employs an embodiment of the present invention;

FIG. 2 is a cross-sectional view of a detector which comprises a portion of the solid state detector imaging system of FIG. 1;

FIG. 3 is a flowchart of a defective pixel correction scheme implemented in the solid state defector system of FIG. 1;

FIG. 4 is a sample image with no defective pixels;

FIG. 5 is a sample map of defective pixels;

FIG. 6 is a sample image using a conventional correction method;

FIG. 7 is a sample image using an embodiment of the defective pixel correction scheme of the present invention;

FIG. 8 is a sample map of pixel differences between the image with no defective pixels of FIG. 4 and the image using the conventional correction method of FIG. 6; and

FIG. 9 is a sample map of pixel differences between the image with no defective pixels of FIG. 4 and the image using an embodiment of the present invention of FIG. 7.

DETAILED DESCRIPTION OF THE INVENTION

Referring to FIG. 1, there is shown the major components of a solid state detector imaging system 10. System 10 includes a detector 12, a readout

electronics 18, a scan electronics 24, a processor 20, and an operator console 30. System 10 is configured to sense photonic energy 34 impinging on the detector 12 and to display an image corresponding to the intensity of such photonic energy on a display device (CRT, LCD, etc.) of the operator console 30. Photonic energy 34 impinges on detector 12, and detector 12 outputs analog signals corresponding to the intensity or energy of photonic energy 34 to readout electronics 18. Readout electronics 18 is coupled to processor 20, and processor 20 is coupled to operator console 30. Scan electronics 24 is coupled to detector 12.

In one embodiment, system 10 is configured to be a x-ray detection imaging system. X-rays are provided by a source and travel through a collimator, to be attenuated by a subject of interest to be imaged, i.e., a patient. Then photonic energy 34 (which in this case are the attenuated x-rays) is received by detector 12 for image display (not shown).

Referring to FIG. 2, detector 12 includes a scintillator 14 and an array of photodetector elements 22. Scintillator 14 converts photonic energy 34 from x-rays to light 16 at wavelengths receivable by photodetector elements 22. For example, scintillator 14 may be comprised of thallium (Tl) doped cesium iodide (CsI) that converts x-rays into visible light. Impinging light 16 is converted into an array of electrical signals by corresponding photodetector elements 22. Although not shown, detector 12 may comprise more than one detector.

Each of photodetector elements 22 includes a photodiode comprised of thin film materials, such as amorphous silicon, and a thin film field effect transistor (not shown). In this manner, each of photodetector elements 22 is configured to output an electrical signal proportional to photonic energy 34 impinging thereon to readout electronics 18 and to be controlled by scan electronics 24, such as being "reset" to acquire the next image.

The readout electronics 18 are configured to convert the array of electrical signals, i.e., analog signals, into an array of digital signals that can be

processed, stored, and displayed as an image using processor 20 and operator console 30. Alternatively, the digitization of the electrical signals can occur in processor 20. Moreover, in order to reduce the amount of readout electronics 18 required in system 10, photodetector elements 22 can be configured to store the electrical signals until they can be processed by readout electronics 18.

Processor 20 is configured to provide electrical signal processing, into an image data form suitable for image display, storage, transmission to a remote site, film or print record, or other utilization and manipulations. Such processing may include performing defective pixel correction (as described in greater detail hereinafter). Operator console 30 includes various components such as a display device, a storage device, a printer, and an operator control unit (e.g., a mouse, a keyboard, a graphical user interface, etc. (not shown)) to facilitate various utilization and manipulation of the acquired image data. Alternatively, operator console 30 may be omitted and the various output modes of the acquired image data may be carried out in processor 20.

Detector 12 includes a plurality of photodetector elements 22. Depending on factors such as the type of desired imaging, resolution, cost of system, etc., detector 12 can vary in size and construction. For example, for x-ray imaging relatively large portions of the test subject, such as the patient's chest area, a 41 x 41 cm^2 active area detector can include several million photodetector elements 22 (e.g., 2048 x 2048 array of photodetector elements 22) with a pixel pitch of 200 x 200 μm^2. As another example, detector 12 may have a smaller active area for use in mammography and have a 100 x 100 μm^2 pixel pitch. In still another example, detector 12 may be housed inside a charge-coupled device (CCD) camera with an active area of only 2 cm^2.

Moreover, it should be understood that system 10 is not limited to x-ray imaging. In another embodiment, system 10 can be configured to acquire images from photonic energy 34 outside the wavelengths of x-rays. Accordingly,

detector 12 may include additional components, or components such as scintillator 14 can be omitted.

Because detector 12 includes a large number of photodetector elements 22, it is not unusual for one or more photodetector elements 22 to be defective. Such photodetector elements 22 are defective because they are not responding photonically or electrically, or because they respond electrically but in a manner statistically different from other photodetector elements 22 with similarly impinged photonic energy 34. Consequently, defective photodetector elements 22 produce defective electrical signals and ultimately defective pixel values in the displayed image, if left unaltered. While it may be unpractical and expensive to refabricate defective photodetector elements 22, it is possible to correct or mask defective pixel values before the acquired image is displayed.

Before such a correction scheme is implemented, defective pixels of detector 12 are identified using one or more conventionally known methods. For example, during calibration and setup of system 10, all the defective pixels of detector 12 can be identified by analyzing known images, e.g., an image containing no structure, and searching for nonconforming or unexpected pixel values. For more details relating to identification of defective pixels, reference is made to U.S. Pat. No. 5,657,400 owned by the General Electric Company, which is incorporated herein by reference. From this identification step, n number of defective pixels can be identified for detector 12.

After a current image has been acquired using detector 12, each defective pixel i in the current acquired image, where $i = 1, 2, \ldots, n$, can be corrected or masked. Referring to FIG. 3, there is shown a flowchart of an image feature or gradient method for correcting defective pixel values. The correction scheme preferably occurs in processor 20 after the array of electrical signals have been converted into digital signals. The correction scheme includes a temporarily replace defective pixel step 42, a select matrices step 44, a determine local gradient step 46, a determine correction value step 48, a replace defective pixel value step

50, a check step 52, and an incrementor step 54. For each defective pixel *i*, steps 42-54 are carried out to provide a correction thereto.

In step 42, the value of defective pixel *i* is temporarily replaced with a linear interpolation of its surrounding neighboring pixel values. Details relating to linear interpolation are provided in U.S. Pat. No. 5,657,400, which has already been incorporated herein by reference. Alternatively, step 42 may be omitted and the correction may be performed without determining the linear interpolation of defective pixel *i*.

After step 42, the selection of matrices A_i and H are carried out in step 44. A_i is a matrix of the pixel values comprising the acquired image with the value of defective pixel *i* temporarily replaced by t_i (in step 42). In the case of a detector 12 including 2048 x 2048 array of photodetector elements 22, A_i can be up to a 2048 x 2048 matrix. Alternatively, A_i can be smaller than a 2048 x 2048 matrix, comprised of t_i, as the center matrix element, and its surrounding neighboring pixels as the remaining matrix elements. For example, A_i may be a 7x7 matrix.

H is a gradient kernel matrix. In one embodiment, H is a 7x7 Laplacian of a Gaussian filter kernel defined by the values:

$$H = \begin{matrix} 0.0235 & 0.0235 & 0.0235 & 0.0235 & 0.0235 & 0.0235 & 0.0235 \\ 0.0235 & 0.0235 & 0.0256 & 0.0355 & 0.0256 & 0.0235 & 0.0235 \\ 0.0235 & 0.0256 & 0.3034 & 0.7128 & 0.3034 & 0.0256 & 0.0235 \\ 0.0235 & 0.0355 & 0.7128 & -5.0694 & 0.7128 & 0.0355 & 0.0235 \\ 0.0235 & 0.0256 & 0.3034 & 0.7128 & 0.3034 & 0.0256 & 0.0235 \\ 0.0235 & 0.0235 & 0.0256 & 0.0355 & 0.0256 & 0.0235 & 0.0235 \\ 0.0235 & 0.0235 & 0.0235 & 0.0235 & 0.0235 & 0.0235 & 0.0235 \end{matrix}$$

In another embodiment, H can be of a different matrix size, such as 11x11 or 5x5. Moreover, H can be a variety of gradient kernels, such as a Roberts, Prewitt, or Sobel gradient kernel. It shall be understood that the matrix size of A_i and the matrix type and size of H can be preset such that step 44 may be omitted.

The selection capability in step 44 provides flexibility in noise immunity vs. edge strength.

After step 44, determination of a local gradient, G_i around temporarily replaced pixel t_i is carried out in step 46. In one embodiment, G_i is calculated by:

$$G_i = \sqrt{(A_i * H)^2 + (A_i * (-H))^2}$$

For example, when A_i and H are both 7x7 matrices, G_i will be a 7x7 matrix. Alternatively, G_i can be determined by a variety of other equations such that G_i provides relative gradient information about the pixels surrounding defective pixel *i* (the surrounding pixels as specified by A_i) with respect to image features, such as a strong edge, embodied by these surrounding pixels. Thus the matrix elements of G_i having the highest values, i.e., strongest gradients, correspond to pixels comprising the strongest image features for that portion of the image.

Using G_i calculated in step 46, a correction value c_i to correct defective pixel *i* is determined in step 48. Correction value c_i is a linear average or a weighted average of the *i*th defective pixel's surrounding neighboring pixel values with the highest gradients and/or closest proximity to defective pixel *i*. Correction value c_i insures that defective pixel *i* is replaced with image information along an image gradient, i.e. based on more global image information such as image features, instead of very local image information only. Any well-known linear averaging or weighted averaging methods can be utilized to determine c_i.

For example, step 48 can comprise a weighted average based on the three highest gradient pixel values within a three-pixel radius of defective pixel *i*. Then the pixel values corresponding to the highest, the second highest, and third highest gradient pixel, respectively, would be given a weight of 50%, 30%, and 20%, respectively. In another example, step 48 can comprise a weighted average based on the three highest gradient pixel values within a three-pixel radius of defective pixel *i* with greater weight given to pixels closer in location to defective

pixel i. Assume that for these three highest gradient pixels, one pixel is located at each of one-pixel, two-pixel, and three-pixel radius of defective pixel i. Then the pixel values located at the one-pixel, two-pixel, and three-pixel radius of defective pixel i, respectively, would be given a weight of 50%, 30%, and 20%, respectively.

Once c_i has been determined in step 48, the value of defective pixel i (actually t_i from step 42) is replaced with the correction value c_i in step 50. If all the defective pixels in a given image have not been corrected (i.e., $i < n$), then step 52 directs the defective pixel correction to be performed for the next defective pixel (i.e., $i = i + 1$ in step 54). Otherwise if all the defective pixels in a given acquired image have been corrected (i.e., $i = n$), then step 52 directs the defective pixel correction process to end for this acquired image. Thus the final image, to be displayed, printed, etc., is the acquired image with correction of its defective pixels.

In FIGs. 4-9, an illustrative comparison of a final image generated using a conventional correction method and a final image generated using an embodiment of the present invention is provided. FIG. 4 is an image containing no defective pixels. The image includes, with respect to the background, a first circle 60 having positive contrast and a second circle 80 having a negative contrast. In FIG. 5, a map of a plurality of defective or bad pixels 62, 82 is shown. Defective pixels 62, 82 are introduced or merged with first and second circles 60, 80, respectively, to form the start or "acquired" image. The defective pixels of this start or "acquired" image are corrected (e.g., the defective pixel map shown in FIG. 5) to generate the final image, using (a) a conventional correction method such as linear interpolation (in FIG. 6), or (b) an embodiment of the gradient method (in FIG. 7).

The advantage of using the gradient method over the conventional method is readily apparent in FIGs. 8 and 9. FIG. 8 shows the pixel differences between the image containing no defective pixels (FIG. 4) and the image corrected with the conventional method (FIG. 6). Similarly, FIG. 9 shows the pixel differences between the image containing no defective pixels (FIG. 4) and the image

corrected with the gradient method (FIG. 7). Thus, the gradient method results in a much smaller number of deviating pixels, i.e., insufficiently corrected or not corrected pixels, than the conventional method. Moreover, the gradient method is better capable of preserving image features and edges, such as features 64, 84 (see FIG. 6), than the conventional method, such as features 66, 86 (see FIG. 7).

While the embodiments and application of the invention illustrated in the FIGs. and described above are presently preferred, it should be understood that these embodiments are offered by way of example only. For example, it is contemplated that the invention may be applied to systems other than medical systems which can benefit from the use of defective pixel correction. Still further, the present invention may be implemented using hardware, software, and/or firmware. Even still further, the correction values of the defective pixels (i.e., c_i) can be linked with its acquired image in a variety of manner, such as permanently replacing the defective pixel values on the acquired image or separately storing the correction values with links to the corresponding defective pixel locations. Accordingly, the present invention is not limited to a particular embodiment, but extends to various modifications that nevertheless fall within the scope of the appended claims.